Prelingual Deafened Cochlear Implant Users' Hot Inhibitory Control Skills

Honors Undergraduate Research Thesis

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Abstract

The absence of auditory input during key periods of cortical development may yield an altered trajectory of neurocognitive development (Kral & Sharmu, 2012). Consequently, prelingually deafened cochlear implant (CI) users present a clinically significant elevated risk for deficits across several domains of executive function (EF), or goal directed behavior (Welsh, Pennington, & Groisser, 1991). One EF domain at risk in CI users is inhibitory control or the ability to inhibit internal impulses in pursuit of an overarching goal (Diamond, 2013). However, all performance-based metrics of inhibitory control used to assess CI users have been emotionally decontextualized (termed cool EF tasks). Yet, there is a growing body of literature among NH populations to suggest that emotionally salient tasks (termed hot EF tasks) require different cortical mechanisms (Happaney, Zelazo, Stuss, 2004; Egner, Etkin, Gale & Hirsch, 2008, Rubia, 2011; Nejati, Salehinejad, Nitsche, 2018). However, hot inhibitory control has yet to be examined among CI users. This thesis project sought to: 1) examine the hot inhibitory control abilities of prelingually deafened CI users and normal hearing (NH) children; and 2) evaluate the relationship between hot and cool inhibitory control in both NH and CI samples. Behavioral metrics suggest that CI users are at risk for significant deficits of hot inhibitory control skills, and that these deficits are not associated with cool inhibitory control. These preliminary findings suggest hot and cool inhibitory control recruit differing cognitive processes, which is important in understanding the longitudinal challenges that the prelingually deafened CI user population face.

I) Introduction & Literature Review

A cochlear implant (CI) is a biomedical device that uses electrodes to stimulate the auditory nerve directly. The advent of this technology has significantly improved the spoken language capabilities of prelingually deafened children (Kirk, Ying, Miyamoto, O'Neil, Lento & Fears, 2002; Nicholas & Geers, 2007; Peterson, Pisoni & Miyamoto, 2010). However, there is evidence that the early auditory deprivation associated with prelingual deafness may initiate an altered neurodevelopmental trajectory. For example, neurological literature on both pediatric and adult populations suggests that the deprivation of auditory input during development may alter physiological aspects of neurodevelopment and result in cortical reorganization (Shibata, 2007; Sharma, Gilley, Dorman, & Baldwin, 2007; Li, Li, Xian, Li, Liu, Liu, Wang, Wang, He, 2012; Kral & Sharma, 2012; Liu, Feng, Yang, Chen, Li, Huang, Zhang, 2015). Furthermore, there is a growing body of literature demonstrating that prelingually deafened CI users perform more poorly compared to their normal hearing (NH) counterparts on a broad range of cognitive tasks including assessments of memory, fluency speed, and inhibition concentration (Figueras, Edwards, & Langdon, 2008; Kronenberger, Pisoni, Henning & Colson, 2013; Beer, Kronenberger, Castellanos, Colson Henning, & Pisoni, 2014; Blank, Holt, Pisoni, & Kronenberger, 2020). Many have theorized that the deprivation and degradation of crucial early auditory experiences that facilitate cortical development may be responsible for observed deficits in executive function (EF) among prelingually deafened CI users (Beer, Pisoni, & Kronenberger, 2009). EF is defined as goal directed behavior and is an umbrella term for a variety of high-order cognitive functions (Welsh, Pennington, & Groisser, 1991). Inhibitory control, the ability to inhibit impulses in favor of the completion of an overarching goal (Diamond 2013), is a specific domain of EF that is negatively affected by prelingual deafness (Figueras et al., 2008; Beer et al. 2014; Kronenberger et al., 2013; Blank et al., 2020).

Among the NH population, poor inhibitory control skills have been associated with academic difficulties (Mischel, Shoda, & Peake, 1998; Waber, Gerber, Turcios, Wagner, & Forbes, 2006; Ponitz, McClelland, Matthews, & Morrison, 2009) as well as negative psychosocial outcomes such as behavioral and emotional problems (Morgan, Farkas, Hillemeier, Pun, Maczuga, 2019; Hentges, Krug, Shaw, Wilson, Chalfant, 2020). For example, Morgan and colleagues (2019) conducted a longitudinal study of over 8,000 second graders with NH, and found that lower inhibitory control skills were associated with poorer math and reading capabilities, as well as more internalized behavioral problems such as feeling anxiety or loneliness (Morgan et al., 2019). Inhibitory control skills have also been associated with distinguishing an auditory stimulus from a background noise (Knijff, Coene, & Govaerts, 2018); which may pose problems in the day to day lives of pediatric CI users, considering that they spend a significant amount of time in background noise (Busch & Wieringen, 2017). Thus, a complete understanding of the inhibitory control delays and/or deficits of prelingually deafened CI users is crucial in understanding their long-term outcomes and daily function.

Inhibitory Control

In recent years, there has been a growing body of literature that demonstrates inhibitory control deficits in pediatric CI users (Figueras et al., 2008; Beer et al. 2014; Kronenberger et al., 2013; Blank et al., 2020). Figueras and colleagues (2008) is one of the first studies to examine inhibition in pediatric CI users compared to their NH counterparts. This study tested twenty-two prelingually deafened CI users as well as twenty-two NH controls, ranging from eight to twelve years of age. To measure inhibitory control skills, a Day-Night task was administered, in which a participant must say “day” when presented a picture of a moon, and “night” when presented a picture of the sun. Inhibitory control was also assessed using a One-Two task, in which when shown the number one, they must vocalize “two” and vice versa. Thus, both tasks require recruitment of inhibitory control skills in order to inhibit vocalizing the appropriate word associated with the picture. Results revealed that CI users had significantly longer latency response times in both the Day-Night and One-Two task when compared to NH controls, suggesting higher cognitive demand was placed on inhibitory control skills among the CI users (Figueras, Edwards, Langdon, 2008).

Kronenberger and colleagues (2013) found additional evidence of inhibitory control deficits among prelingually deafened participants. Participants ranging from seven to twenty-five years of age, who received CI surgery prior to seven years of age, were matched by age and non-verbal intelligence to NH counterparts. This study examined several domains of EF, including inhibitory control skills. Three tasks were administered to assess inhibitory control skills: the Test of Variable Attention (TOVA), Trail Making, and Stroop-Word. In TOVA task, participants were asked to press a button when a square was presented at the top of the screen. However, when that same visual cue was presented at the bottom of the screen, they were asked to inhibit this overlearned response and not press the button. Three metrics were assessed: 1) omissions (i.e., failed to response to target square at the top of the screen); 2) commissions (i.e., responding inaccurately to non-target square at the bottom of the screen); and 3) response time. In the Trail Making Task, participants were presented with an array of randomly placed numbers and letters and asked to connect them in order. However, they were asked to switch back and forth between letters and numbers (e.g., A-1-B-2). Finally, in the Stroop Word Task, participants were presented a series of color words (i.e. “red”, “blue”, etc.) that were written in a font color different from the color word itself. Thus, participants were required to suppress the overlearned behavior of reading the word and in favor of naming the ink color instead. Results of the TOVA task revealed that CI users performed significantly more poorly on all 3 metrics compared to their NH counterparts. CI users also performed significantly more poorly on the Trail Making Task as well. On the Stroop Word Task, CI users scored more poorly, but it was not statistically significant. However, researchers noted that a child's version of the Stroop Color Word Task table was used, even though some participants exceeded the ages on the task's norm table. This study provides evidence that prelingually deafened CI users are at risk for longitudinal deficits in inhibitory control skills.

A study by Beer and colleagues (2014) also provides evidence of inhibitory control deficits among prelingually deafened CI users. However, this study served as the first to demonstrate that these deficits emerge as early as preschool. Beer et al. (2014) used the Attention Sustained subset of the Leiter International Performance Scale as a metric of inhibitory control. This timed task requires an individual to manually cross off selected target picture (such as a flower) in a field of distracting non-target stimuli (e.g., different flowers, butterflies, mushrooms). Thus, participants must ignore the nontarget distractors in order to complete the task. Results revealed that CI users scored significantly more poorly on this metric than their NH counterparts, with 27% scoring within the clinically significant range (one standard deviation (*SD*) below the normative mean). Of note, no NH participants performed within the clinically significant range. This study demonstrates that preschool aged CI users, who received their CI prior to the age of three, are also at risk for deficits in inhibitory control skills. (Beer, Kronenberger, Castellanos, Colson, Henning, & Pisoni, 2014).

A recent study by Blank and colleagues (2020) provides additional evidence of inhibitory control deficits among the prelingually deafened pediatric population. A cohort of twenty-nine prelingually deafened CI and prelingually deaf Hearing Aid (HA) users were compared to twenty-eight NH counterparts. Children ranged from three to seven years of age. A Flanker task from the NIH Toolbox iPad Cognition Battery was used as a metric of inhibitory control. For the Flanker task, children were first asked to indicate the direction of a central fish while ignoring distractor fish. If the children scored 90% or above on the fish stimuli, they moved on to trials that use arrows rather than fish. Of the twenty-eight NH participants, twenty-five were able to score 90% or above on the fish trials and move onto the arrow trials. Contrarily, only nineteen of the twenty-nine prelingually deaf subjects were able to move past the fish trials. As expected, the CI users and HA users performed significantly poorer on the Flanker task compared to NH counterparts (Blank, Holt, Pisoni, & Kronenberger, 2020).

In addition to direct metrics, there is a parallel body of literature utilizing EF parent-reporting questionnaires that provide complementary evidence of inhibitory control deficits in the pediatric CI population. A questionnaire which has been extensively utilized in pediatric CI studies is the Behavioral Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy & Kenworthy, 2000) as well as BRIEF-Preschool Version (BRIEF-P; Gioia, Espy, & Isquith, 2003). The BRIEF assesses multiple domains of EF, including inhibitory control, as it would appear in everyday life. More specifically, this questionnaire asks the parent to rank how often a given behavior is problematic for his/her child on a scale of Never (0), Sometimes (1), or Often (3). A higher score reflects more deficits in a given domain. One of the first studies to utilize the BRIEF in the pediatric CI population was Beer and colleagues (2011). This study administered the BRIEF to the parents of forty-five CI users between the ages of five to 18 years. All subjects received CI surgery prior to the age of seven years. Results revealed that CI users scored significantly poorer on the BRIEF inhibit subscale compared to the normative BRIEF mean (Beer, Kronenberger, & Pisoni, 2011). Similar findings were later found among preschool aged children, with 45% of CI users scored within the clinically significant range, whereas only 15% of NH scored within the clinically significant range (Beet et al., 2014). A disproportionate amount of prelingually deafened CI users scoring within the clinically significant range is also seen in the Holt and colleagues (2013) study (Holt, Beer, Kronenberger, Pisoni, 2013). Thus, the BRIEF has provided consistent evidence for clinically significant deficits in inhibitory control among this CI and HA users (Beer et al., 2011; 2014; Holt, et al., 2013; Kronenberger et al., 2013).

It is important to note that direct metrics of inhibitory control, like the Flanker, are emotionally decontextualized in design, meaning the task does not elicit a strong emotional response. However, the majority of the day-to-day activities preschool aged children face will have emotional undertones (e.g., waiting in line for lunch, waiting their turn to speak). Instances of emotionally motivated EF processing is described as “hot” EF, whereas “cool” EF is emotionally decontextualized (Zelazo & Carlson, 2012). By only utilizing cool tasks of inhibitory control, a complete picture of inhibitory control deficits cannot be developed. Past studies utilizing parent-reported BRIEF questionnaires provide evidence that prelingually deaf CI users struggle in the recruitment of inhibitory control skills in their day-to-day lives. However, no studies have yet explored the expression of hot inhibitory control among prelingually deaf CI users using behavioral tasks. Understanding the expression of hot inhibitory among this population may yield more ecologically valid insights.

Distinguishing Between Hot and Cool EF

There is a body of neurological literature to suggest that the EF skills needed to complete hot versus cool tasks are different. For example, there is evidence that hot EF tasks recruit more activation of the orbitofrontal cortex, whereas tasks of cool EF tasks do not (Happaney, Zelazo, Stuss, 2004; Egner, Etkin, Gale & Hirsch, 2008, Rubia, 2011; Nejati, Salehinejad, Nitsche, 2018) Additionally, there is evidence that damage to localized cortical areas (e.g., orbitofrontal cortex) can produce deficits in hot EF without the presence of deficits in cool EF (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Tranel, Anderson, 1998; Zelazo & Carlson, 2012). Furthermore, there is evidence that hot and cool EF skills follow distinct developmental trajectories throughout adolescence (Prencipe, Kesek, Cohen, Lamm, Lewis, Zelazo, 2011; Aite, Cassotti, Linzarini, Osmont, Houde, Borst, 2016; Poon, 2018), suggesting that each involve different cognitive mechanisms.

While there is evidence to suggest distinct qualities between hot and cool EF skills, there is little research focusing on the subdomains of hot and cool inhibitory control specifically. Distinctions between hot and cool inhibitory control were explored in a study by Kim and colleagues (2012). This was a longitudinal study of one hundred NH subjects, who were first tested between the ages of three and four years old. Similar to abovementioned studies, a Day-Night task was used as a metric of cool inhibitory control. Additionally, a Snow-Grass task was also used as a metric of cool inhibitory control. Subjects were required to point to a green chip when they heard the word “snow” and point to a white chip when hearing the word “grass”. A snack delay and gift delay tasks were used to measure hot inhibitory control. The snack delay task consisted of four trials in which participants were required to wait to retrieve an M&M from under a clear cup. Their behavior was scored based upon their ability to delay retrieving the treat.

The gift delay task had multiple components; assessing the child's ability to wait for a gift to be wrapped without peeking, wait for a bow to be placed on the bag, and wait to retrieve the gift. This study used a composite score which reflected multiple behaviors such as peeking, touching the bag, and the latencies of looking at/opening the gift. These two tasks recruited inhibitory control skills by requiring participants to override the temptation of retrieving the rewarding stimulus, in favor of complying with the instructions. Later, when subjects were between five and eight years of age, parents and teachers rated the academic (e.g., math and reading abilities) and behavioral (e.g., conduct disorder, anxiety disorder, depression, and OCD) outcomes of the children three different times using the MacArthur Health Behavioral Questionnaire and the Child Symptom Inventory-4 questionnaires respectively. Based on significant correlations, children who demonstrated poorer inhibition skills in the presence of an emotionally motivating reward (i.e., gift or M&M) were more likely to exhibit behavioral problems later in childhood. In contrast, performance on the cool EF task did not significantly predict behavioral problems. Cool inhibitory control performance was predictive of academic outcomes, but not for behavioral outcomes (Kim, Nordling, Yoon, Boldt, Kochanska, 2013). This study provides evidence that observable distinctions can be made between hot and cool inhibitory control skills, and that these two subdomains can be used to predict different long-term outcomes. More specifically, hot EF tasks provide insight into behavioral outcomes for NH children.

Although subjective data from parent-report questionnaires may provide some insight into the hot inhibitory control abilities of CI children, there is currently no study that examines these real-world skills using a direct metric such as snack and gift delay. Furthermore, as demonstrated by Kim et al. 2013's results, cool inhibitory control performance only predicts academic performance in the NH population. Therefore, only examining the cool inhibitory control abilities of pediatric CI users provides an incomplete picture of affective and psychosocial application of inhibitory control skills. Understanding hot, in addition to cool, inhibitory control abilities has great potential to yield a more complete understanding of the everyday challenges this population may face.

Current Study

The present study sought to: 1) examine the hot inhibitory control abilities of prelingually deafened CI users and their NH peers with behavioral and questionnaire metrics; and 2) evaluate the relationship between hot and cool inhibitory control in both NH and CI samples. It was predicted that CI users would perform significantly more poorly on behavioral and questionnaire metrics of hot inhibitory control than their NH counterparts. Furthermore, as a secondary prediction, it was expected that CI users would perform significantly more poorly on a metric of cool inhibitory control. A complete understanding of hot inhibitory control skills among CI users will allow future research to more precisely predict longitudinal outcomes and create more effective interventions.

II) Methods

Participants

Twelve children between three and six years of age who were part of a larger longitudinal study participated in the present study. The twelve participants were divided into two groups, NH (N = 6) and CI (N = 6). All NH participants were administered a pure-tone hearing screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz and had normal language per parent report. Additionally, the *Sentence Structure*, *Word Structure*, and *Expressive Vocabulary* subscales of the Clinical Evaluation of Language Fundamentals-Preschool were administered as an assessment of language skills (CELF-P; Wiig, Secord, & Semel, 1992). All participants in the CI group had bilateral prelingual deafness, with at least one CI activated for a minimum of one year. NH and CI participants were matched 1:1 based on age and nonverbal intelligence using the Primary Test of Nonverbal Intelligence (PTONI; Ehrler & McGhee, 2008), which was administered by a trained examiner. Participants scoring less than seventy on the PTONI were not included in present study.

Testing was administered in a quiet room. Two Go Pro cameras were placed on opposite sides of the room in order to ensure the child was visible throughout the entire experiment. Videos were then coded by two trained student research assistants at a later date.

Behavioral metrics

Toy Frustration

A behavioral Toy Frustration Task was used as a metric of hot inhibitory control. In this task, the child is given a locked transparent box containing a toy (e.g. a bouncy ball, stamp, dinosaur figure) with a set of "dummy" keys which do not unlock the box. The child was instructed to attempt to open the box while the experimenter leaves the room for four minutes. Once the task was complete, the experimenter provided the child with the working key and the child was able to obtain his or her prize. Prior to the beginning to this task, the child was trained on how to unlock a pad lock using a separate set of practice keys.

For coding purposes, the 4-minute Toy Frustration Task was divided into sixteen fifteen-second intervals. Three distinct indices were created to quantify the child's behavior in each interval: 1) Engagement; 2) Frustration; and 3) Parent Seeking. **Engagement** assessed the child's willing participation in the task and was coded in a binary fashion as follows: 1= the subject physically touched the box during the fifteen-second interval, and 0= the subject did not touch the box. Thus, a lower Engagement score is indicative of poorer performance on the task.

Frustration was coded as a metric of the child's frustration towards their inability to open the box. The frustration scale is as follows: 1= *Concentration with No Frustration*; 2= *Mild Frustration* (e.g., any vocal or physical behavior that indicates the initial stages of frustration/sadness such as whining, grunting, whimpering, arms crossed); 3= *Overt Frustration* (e.g., any vocal or physical behavior that indicates obvious and intense frustration/sadness such as crying with extreme tears, yelling, throwing a fit, shaking/throwing/banging on box, stomping feet, clenched fists); and N= *None* (i.e., child is not participating in the task).

Parent/Experimenter Seeking Behavior was coded using a 4-tier intensity scale: 0=*No Parent Seeking*, 1= *Low* (e.g., mild vocalizations/whimpering for parent,) 2= Moderate (e.g., overt behaviors such as running up to door/ one-way mirror), and 3= *High* (e.g., crying, yelling, opening/attempting to open door).

Gift Delay

Next, a Gift Delay Task was administered, which was also used as a metric of hot inhibitory control. This task was comprised of two parts. In Gift Delay Part One, a trained researcher entered the room and presented the child with a gift bag. The researcher oriented the child facing a blank wall and instructed the child not to turn around while the gift was being wrapped. The researcher proceeded to loudly crumble the tissue paper for one minute. After one minute has elapsed, the child was oriented to face the gift bag, which was now stuffed with tissue paper and sitting on the table. For Gift Delay Part Two, the researcher informed the child that before they were allowed to open the bag, a bow must be placed on top of the gift. The child was instructed not to peak at the gift while the researcher was out of the room searching for the bow. After three minutes have elapsed, the researcher returned with the bow, placed it on the gift bag and the child was able to open the gift.

Like Toy Frustration, Gift Delay was also divided into fifteen-second intervals. Child Peeking was quantified for the first minute of the Gift Delay, in which the child faced the wall. For each interval, a binary *Yes= 1* or *No= 0* was coded if the child turned around at any point during a given interval. If the child did peek during an interval, both the frequency of peeks and duration in seconds were quantified.

A separate coding scheme was used for the second part of Gift Delay in which the child is facing the gift. Each of the following were coded as a binary Yes= 1 or No= 0 for each interval: **1) On Seat**: At any point during interval the child touches the seat, **2) Touching Bag**: Any part of the child's body is in contact with the bag, if coded "Yes" both frequency and duration of touch was recorded, **3) Opening/Peeking In**: Child is gazing into the interior of the bag -or- child is pulling the bag open with the intention of seeing the gift, **4) Hand in the Bag**: Child puts hand(s) in the bag -or- touches/handles the tissue paper inside the bag, but not the gift, **5) Pulling Gift from Bag**: Gift is made visible to the coder as a result of the child's behavior. The findings of these five metrics were reported as the percentage of intervals these behaviors were present in. Additionally, the metric **Look Away** assessed a child's avoidance of eye contact with the gift bag. Individual time stamps of when the child made and diverted eye contact with the bag were recorded, and the frequency and total duration (in seconds) that the child looked away from the bag was quantified. Finally, the metric **Intervals Before Deviance** reflected the number of intervals a participant delayed gratification before engaging in the following "deviant" behaviors: Touching Bag, Opening/Peeking In, Hand in Bag or Pulling Gift from Bag.

The Toy Frustration and Gift Delay tasks were checked for reliability using the following scheme: (1) A primary coder independently coded all intervals for both tasks, (2) A second researcher also coded all data independently, (3) Each interval was then consulted upon until a consistent interpretation of the coding scheme was established. This was achieved through re-watching videos and recoding select intervals. Moreover, if needed, a third coder was consulted in making a determination. Inter-rater reliability of 100% was achieved for all of the data.

During the testing session, the accompanying parent completed several questionnaires, including The Behavioral Rating Inventory of Executive Function Preschool Version (BRIEF-P, BRIEF; Goia, Isquith, Guy & Kenworthy), a sixty-three-item questionnaire inquiring the frequency a given behavior has been seen as problem within the past six months. Such items included “Has trouble concentrating on games, puzzles, or play activities” and “Needs help from an adult to stay on task.” Parents may answer with one of three responses: *never*, *sometimes*, or *often*. The BRIEF-P uses a severity score, meaning that a higher rating is indicative of having more EF problems. For the purpose of this study, only the *Inhibitory Self-Control* index was analyzed. This index is comprised of the *Inhibit*, *Shift* and *Emotional Control* subscales (Gioia, Espy, Isquith 2003; Gioia, Isquith, Guy, Kenworthy, 2000).

Flanker

The National Institute of Health (NIH) Toolbox (Zelazo, et al., 2013) Flanker Task was used as a measurement of cool inhibition. This task was administered on an iPad by a trained researcher. Instructions were provided with visual cues and auditory instructions. Subjects were first presented with five practice trials. Each trial presented an array of five fish, either facing left or right. The display of fish could be in one of two conditions: 1) congruent (i.e., all fish are facing in the same direction), or 2) incongruent (i.e., all fish with the exception of the middle fish are facing the same direction; see Figure 1). At the bottom of the screen, participants were presented with two arrows facing left or right and were asked to press the button that corresponded to the direction of the middle fish. Upon successful completion of the five practice trials, participants were tasked with selecting the arrow that corresponded to the directionality of the central fish while for twenty experiment trials. Upon completion of the fish trials with 90% accuracy or greater, twenty additional trials were administered. In these additional trials, the fish icons were changed to arrows and a "home base" was introduced**.** During the arrow trials, after each trial, the child was instructed to touch "home base" which was a blue dot on a piece of paper in a fixed position adjacent to the iPad (see Figure 2). This created a consistent distance each trial would begin from, which helped to more precisely calculate reaction time. Thus, reaction time was only obtained during the arrow trials. Performance on either the fish, or both the fish and arrow trials, were used to calculate an age adjusted Flanker score (Gershon, Wagster, Hendrie, Fox, Cook, & Nowski, 2013).

III) Results

CI users and NH peers ranged in age from 3.38 – 6.16 years. Groups (CI, NH) did not differ on gender, ethnicity/race, maternal education, or income (see Table 1). Two tailed *t*-tests were computed for all group differences. As expected, due to the matching protocol, there was no significant difference in nonverbal intelligence as measured by the PTONI ($t(10) = -0.27$, $p = 0.79$). However, as expected, CI users exhibited poorer language skills compared to their NH peers as measured by CELF-P ($t(9) = -2.41$, $p = 0.04$; see Table 2).

Metrics of Hot Inhibitory Control

Toy Frustration

Table 3 contains means and standard deviations for the Toy Frustration Task. The three metrics of interest were Engagement (the percent of intervals participants engaged with the task and attempted to solve the key-box puzzle), Frustration (the severity of negative affect in response to the task), and Parent Seeking Behavior (the degree to switch they attempted to seek a parent/experimenter). CI users and NH peers were comparable on amount of Engagement ($t(10) = -1.52$, $p = 0.16$) with the task.

CI users' Frustration scores ranged from 1.08 – 2.56, whereas their NH peers' Frustration scores ranged from 1.00 – 1.35. On this metric, a score of 1 signifies concentration with no frustration throughout the entire task, whereas a score of 3 signifies overt frustration throughout the entire task. Although group scores trended towards significance, the groups were not statistically different ($t(9) = 2.09$, $p = 0.07$). A metric of percent frustration was computed as the percentage of total intervals in which participants showed any degree of frustration [either mild (a score of 2) or overt frustration (a score of 3)], and these results revealed significant group differences ($t(9) = 2.49$, $p = 0.04$), such that CI users displayed frustration on 51% of intervals, whereas NH peers displayed frustration in only 11% of intervals.

Parent Seeking scores for CI users and NH peers were comparable. Similarly, a measure of Percent Parent Seeking was computed as the percentage of intervals in which participants displayed any degree of parent seeking behavior [either low (a score of 1), moderate (a score of 2), or high (a score of 3)], and results on this measure revealed no group differences ($t(10) = 1.50$, $p = 0.17$). CI users displayed parent seeking behavior on 29% of intervals, whereas NH peers displayed parent seeking behavior on 5% of intervals.

Gift Delay

Table 3 also contains the means and standard deviations for all metrics of Gift Delay Parts One and Two. Gift Delay Part One refers to when the child was facing the wall while the experimenter wrapped the gift. Gift Delay Part Two refers to when the child is in the room alone facing the bag on the table. The two metrics on Gift Delay Part One were On Seat (the percentage of intervals the child remained seated) and the broad metric of Peeking (the degree to which the child turned around and peeked at the gift while the experimenter was wrapping the gift). All participants remained seated for the entirety of Part One of the Gift Delay. Furthermore, all NH participants completed the entire task without peeking, while two of the six CI participants peeked. This metric did not yield significant differences between groups.

Our metrics of Gift Delay Part 2 were the metrics of On Seat (child remained seated for all intervals), Look Away (child diverted eye contact from the bag), Touching Bag (child touched the gift bag), Opening/Peeking Into Bag (child opened / peeked into gift bag), Hand in Bag (child placed hand fully inside gift bag), and Taking Gift From Bag (child removed gift from bag). All NH participants remained seated for the entirety for the task, whereas two CI users left their seat. This metric did not yield significant differences between groups.

The metric of Touching Bag Frequency assessed the total sum of times participants touched the gift bag throughout the entirety of the task. Between groups, the Touching Bag Frequency metric was comparable, with both groups touching the bag between 0 – 5 times respectively. Furthermore, Touching Bag Duration assessed the total time (in seconds) that participants were touching the bag. Among NH participants, the total time an individual participant spent touching the bag ranged between 0 – 5 total seconds. However, among CI users, total seconds spent touching the bag ranged from 0 – 28 seconds, with two participants touching the bag for more than a total of 20 seconds. Yet, these differences in duration were not statistically significant. Additionally, there was no significant difference between groups for the metric of Opening/Peeking into Bag, nor did any participants across groups put their hand into the bag or take the toy from the bag.

Intervals Before Deviance was the last metric of Gift Delay Part Two and assessed the number of intervals a participant delayed gratification prior to engaging in deviant behaviors (e.g., Touching Bag, Opening/Peaking In, Hand in Bag or Pulling Gift from Bag). A score of 0 signified an inability to inhibit one of these deviant behaviors within the first 15 seconds of the task. A score of 12 indicated the completion of the entire task without any deviances. Three of the six NH participants received a perfect score on this metric. Only one CI user received a perfect score, however this was the only participant across both groups to receive a 0% for the On-Seat metric. Meaning, the participant did not remain in the seat facing the gift for the entire duration of the task, whereas all NH participants who received a perfect score remained seated in the seat for every interval. Nonetheless, this metric did not yield significant group differences either.

BRIEF-P

Table 4 contains the means and standard deviations of BRIEF-P questionnaire. This thesis project only utilized three subscales of BRIEF-P questionnaire, relevant to hot EF: 1) *Inhibit*, 2) *Shift*, and 3) *Emotional Control*. These parent-completed subjective metrics reflect each respective subdomain in a real-world scenario with emotional undertones. One parent of a CI users did not complete this questionnaire, resulting in a $N = 11$ sample size for this metric. On the *Inhibit* subscale, CI users did not differ significantly from NH peers. The *Shift* subscale revealed significant differences between groups, with CI users scoring poorer than their NH peers ($t(9) = 2.37$, $p = 0.04$). Differences between groups were negligible on the *Emotional Control* subscale.

Relationships Between Hot and Cool Metrics of Inhibitory Control

The means and standard deviations of Flanker can be found in Table 4. One CI participant did not complete the Flanker task due to behavioral problems, thus the sample size for this task was $N = 11$. Moreover, of the 5 CI users who completed the Flanker, all completed the fish trials successfully and moved onto the arrow trials. Of the 6 NH participants, only 3 performed well enough to move onto the arrow trials. For those who did not complete the arrow trials, reaction time was not used to in the computation of age corrected standard scores. Results revealed no significant difference in cool inhibitory control skills between CI users and their NH peers ($t(9) = -0.06$, $p = 0.95$).

Pearson product correlations were conducted on direct metrics of hot inhibitory control (Gift Delay and Toy Frustration) with commonly used standardized metrics of inhibitory control (BRIEF-P and Flanker), collapsing across groups to examine associations between hot and cool inhibitory control skills (see Tables 5a-5c). Results revealed that Flanker did not significantly correlate with any of the metric of Gift Delay or Toy Frustration task. In other words, Flanker, a standardized metric of cool inhibitory control, was not associated with any of the behavioral metrics of hot inhibitory control employed in this thesis project.

As mentioned above, BRIEF-P is a subjective questionnaire more likely to reflect hot EF. Collapsing across groups, there were significant associations between BRIEF-P and metrics of the Toy Frustration. Both the *Inhibit* and *Shift* subscales significantly correlated with several metrics of the Toy Frustration task (see Table 5a). More specifically, participants whose BRIEF-P scores reflected poorer inhibition and shifting skills were more likely to disengage from the task, become frustrated, and engage in more parent seeking behavior than those with better inhibition and shifting skills. Additionally, on Gift Delay, the *Inhibit* subscale was negatively associated with On Seat, meaning those with worse parent reported inhibition remained on the seat less often. Both *Shift,* and *Emotional Control* subscales were negatively associated with Look Away Frequency, while *Emotional Control* positively correlated with Look Away

Duration. This suggests that participants with worse inhibitory self-control looked away from the gift bag less often, but for a longer total duration.

There was a significant negative correlation between the BRIEF *Emotional Control* subscale and the Flanker ($t(10) = -0.69$, $p = 0.01$). Across groups, children whose parents reported poorer Emotional Control skills performed poorer on the Flanker task. Furthermore, across groups, the BRIEF *Inhibit* subscale also trended towards a negative association with Flanker ($t(10) = -0.46$, $p = 0.09$).

We also examined if associations between hot tasks (Toy Frustration, Gift Delay, and BRIEF-P) and cool inhibitory control (Flanker) differed for CI users and NH peers (see Tables 6a-6c, 7a-7b). One point of distinction between groups, is that within the CI group, the *Inhibit*, *Shift*, and *Emotional Control* subscales of the BRIEF-P significantly negatively correlated with Look Away Frequency on the Gift Delay task, suggesting that CI users whose parents reported poorer inhibitory self-control skills diverted their eye contact away from the gift bag less often. Additionally, among CI users, *Emotional Control* was positively correlated with Look Away Duration ($r = 0.98$, $p = 0.002$), suggesting that CI users whose parents reported poorer emotional control in daily living spent a longer total amount of time looking away from the gift bag during the Gift Delay task. While not statistically significant, a similar trend was seen for *Inhibit* ($r = 0.75$, $p = 0.07$) and *Shift* ($r = 0.68$, $p = 0.11$) scores and Look Away Duration. Together, these results suggest that CI users with poorer reported inhibitory self-control skills look away from the gift bag a smaller number of time but stayed looking away for a longer duration of time.

Among NH participants, there were no significant associations between BRIEF and metrics of Look Away. However, there was a significant negative correlation between *Shift* and Opening/Peeking into Bag ($r = -0.83$, $p = 0.02$).

IV) Discussion & Conclusions

The purpose of this thesis project was to 1) examine the expression of hot inhibitory control among prelingually deafened CI users and their NH peers; and 2) evaluate the relationship between hot and cool inhibitory control in both NH and CI samples. Partial evidence of hot inhibitory control deficits among prelingually deafened CI users was found. The presence of hot inhibitory control deficits in CI users fits into a growing body of literature suggesting that CI users are at an increased risk for a broad set of neurocognitive deficits (Figueras et al., 2008; Kronenberger et al., 2013; Beer et al., 2014). Moreover, preliminary findings suggest that underlying mechanisms may be differentially recruited when children engage in hot and cool inhibitory control tasks.

Expression of Hot Inhibitory Control

The first primary purpose of this thesis project was to explore the expression of hot inhibitory control among prelingually deafened CI users. This project found partial evidence supporting the hypothesis that prelingually deafened CI users display deficits in hot inhibitory control as compared to their age and IQ matched peers. More specifically, significant differences on the Toy Frustration task suggest that CI users have more difficulty exerting inhibitory control over negative affect during emotionally salient tasks. These findings expand upon previous literature that demonstrate that prelingually deafened CI users are at an elevated risk for deficits in cool inhibitory control (Figureras et al., 2008; Kronenberger et al., 2013; Beer et al., 2014; Blank et al., 2020), by providing evidence that inhibitory control deficits are present in hot emotionally salient situations as well. Furthermore, these results suggest that CI users may struggle in recruiting inhibitory control skills in day-to-day emotionally motivated situations.

Performance on the Gift Delay task reveled no significant group differences, although CI users on average performed poorer than their NH peers. Toy Frustration, but not Gift Delay, may have yielded significant group differences because it placed greater demand on "hot" cortical processes. It may be that the Toy Frustration task prompts initial positive affect, which fairly quickly turns to negative affect when they realize that none of the keys work to open the lock. Additionally, the onus of responsibility is on the participant to figure out how to obtain the prize (locked inside the box), whereas in Gift Delay the participant had to inhibit physical positive anticipation and wait patiently. For these reasons, the Toy Frustration task is likely more taxing on hot cortical processes. Additionally, we coded for the expression of emotion in the Toy Frustration task, whereas we only coded for overt physical behaviors in the Gift Delay task. These factors may explain the significant differences seen between the groups in Toy Frustration, but not Gift Delay.

The BRIEF-P (*Inhibit, Shift,* & *Emotional Control* subscales) provided additional evidence of disparities in hot inhibitory control among pediatric CI users and their NH peers. The *Shift* subscale score was significantly poorer among CI users compared to NH peers. Shifting attention away from an emotional enticing stimulus or an unwanted negative emotion is important in exercising inhibitory control. The *Inhibit* subscale score was not statistically significant between groups, although CI users had a mean difference of over 10 points (representing one standard deviation) higher (poorer). Previous studies using larger sample sizes have provided BRIEF findings also reflecting inhibitory control deficits among CI users (Beer et al., 2011; 2014; Holt, et al., 2013; Kronenberger et al., 2013).

Relationships Between Hot and Cool Inhibitory Control

The second objective of this thesis project was to determine the relationship between hot and cool inhibitory control among CI users and their NH peers. We sought to explore if CI users' poorer performance on hot inhibitory control tasks would mirror previous literature findings demonstrating poorer cool inhibitory control skills (Figueras et al., 2008; Beer et al. 2014; Kronenberger et al., 2013; Blank et al., 2020).

In order to test this aim, the Flanker task was utilized as a standardized measure of cool inhibitory control. Contrary to both predictions and previous literature (Figueras et al., 2008; Beer et al. 2014; Kronenberger et al., 2013; Blank et al., 2020), no significant difference in cool inhibitory control was found between CI users and their NH peers. The small sample size of this thesis study could explain why no significant group difference were observed. However, both BRIEF and Toy Frustration Tasks were significantly different across groups, despite this small sample size, which preliminarily suggests that inhibitory control deficits among CI users may be more pronounced in emotionally salient situations.

Correlational analyses revealed further distinctions between the hot and cool forms of inhibitory control. Collapsing across groups, cool inhibitory control (Flanker) was not associated with any direct metric of hot inhibitory control (Toy Frustration or Gift Delay). However, subscales of the BRIEF-P, which reflect hot inhibitory control, were significantly associated with performance on hot inhibitory control tasks (See Table 5a). Similarly, Kim and colleagues (2013) also found distinctions between hot and cool inhibitory control associations in NH children (Kim et al., 2013). Thus, hot and cool EF abilities may derive from differing cortical functions (Bechara et al., 1998, Brock et al., 2009, Zelazo & Carlson 2012), which are both negatively affected by the global deficits caused by prelingual deafness.

Additionally, of the significant correlations between BRIEF and performance on the Toy Frustration, five of these associations persisted across the CI group. However, none of these significant associations persisted across the NH group. For example, collapsed across groups, participants with poorer BRIEF *Inhibit* scores were more likely to seek out their parent. Figure 4 shows that among CI users this correlation remained strong whereas for NH participants there was no association. In other words, CI users with poorer parent rated inhibitory self-control skills were more likely to perform more poorly on emotionally salient tasks of inhibitory control. Whereas for NH participants there was no association. This preliminarily suggests that these hot tasks may have been more challenging for the CI group and required more EF recruitment.

Associations between BRIEF and performance on the Gift Delay also revealed additional differences between CI and NH hot inhibitory control skills. CI users with poorer BRIEF scores tended to look away from the bag less frequently, but for a longer duration of time. This may be reflective of an overt compensatory behavior that some CI participants with poorer inhibitory control used to stay on task, as seen in previous delay of gratification studies (Mischel & Ebbesen, 1970).

Lastly, results revealed an association between performance on Flanker and the *Emotional Control* subscale of BRIEF, as well as a trend towards significance with the *Inhibit* subscale. Thus, participants with better inhibition and shifting skills performed better on the metric of cool inhibitory control. This may suggest that the BRIEF is reflective of both aspects of hot and cool inhibitory control. While this study provides preliminary evidence for the recruitment of differing mechanisms on hot and cool inhibitory control tasks, the correlation between a cool inhibitory control metric and a relatively hot questionnaire may be reflective of the presence of some shared mechanisms between hot and cool inhibitory control.

Implications & Future Studies

This thesis study provides preliminary evidence to suggest that prelingually deafened CI users perform more poorly on behavioral metrics of hot inhibitory control. The presence of deficits in hot inhibitory control skills among CI users is important, as previous research with NH typically developing children has suggested that hot inhibitory control is more associated with behavioral problems than cool inhibitory control (Kim et al., 2013). This is clinically relevant, as this suggests CI users' with deficits in hot inhibitory control may be at risk for future behavioral problems.

Additionally, this study found differential associations between hot and cool inhibitory control. Previous research often uses standardized metrics of inhibitory control (e.g., Flanker or BRIEF) to quantify inhibition as a unidimensional domain of EF. However, given the evidence that hot and cool inhibitory control may recruit differing cortical processes, future research should be cognizant of where on the hot vs. cool spectrum a given metric of inhibitory control falls. Furthermore, understanding the differential longitudinal associations of hot and cool inhibitory control is essential in creating effective interventions for preschool aged CI users. More specifically, an intervention aimed at improving "cool" inhibitory control skills may also access how inhibition skills can lead to generalized improvements in behavioral problems.

Future studies should also recruit a more robust sample of participants to validate these preliminary finding. Furthermore, this study demonstrated that there is added value in investigating EF in both hot and cool forms. Future pediatric CI studies should investigate the expression of other domains of EF in emotionally salient contexts. Understanding the expression of all domains of EF in emotionally salient situations will allow for a fuller understanding of the broad set of neurocognitive deficits associated with prelingual deafness. Moreover, further explorations of this nature may yield additional insights into the day-to-day expression of EF, and the potential challenges pediatric CI users may face longitudinally.

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Appendix A: Figures

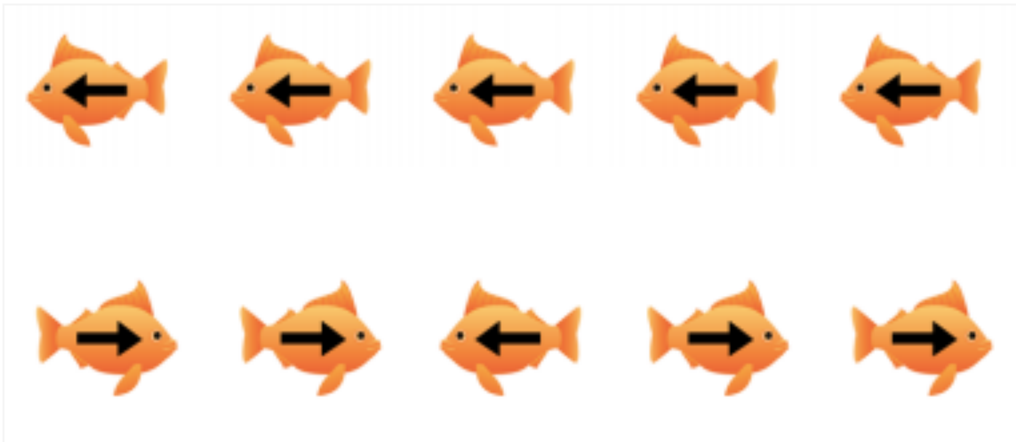

Figure 1a: Shown above are the "fish" trials of the Flanker Inhibitory Control and Attentional Test of NIH Toolbox. The uppermost row represents the congruent condition, meaning that the central representation is facing in the same direction as the flanking representations. The bottom row represents the incongruent condition, meaning that the central representation is facing a different direction from the flanking representations. Participants must inhibit flaking representations in order to indicate the directionality of the central representation. Children were only presented 1 row of stimuli at a time.

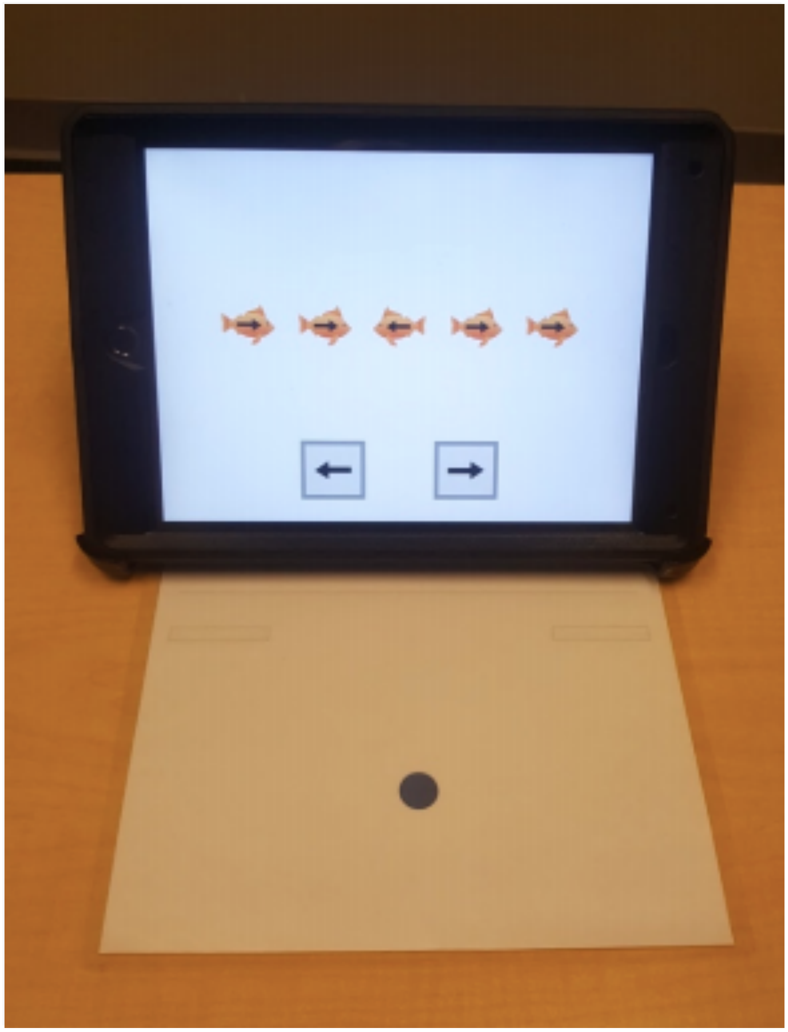

Figure 1b: Above is the set up for the Flanker Inhibitory Control and Attentional Test of NIH Toolbox. Upon the completion of the “fish” trials, as shown above, participants move onto the “arrow” trials, in which the arrows are no longer superimposed on images of fish. Arrow trials require participants to tap home base (i.e., the blue dot above) in between trials. This creates a standardized distance a participant’s hand moves before trials. This yields more precise measurements of reaction time.

Figure 2a: Associations between BRIEF *Inhibit* Score and Engagement Collapsed across Groups

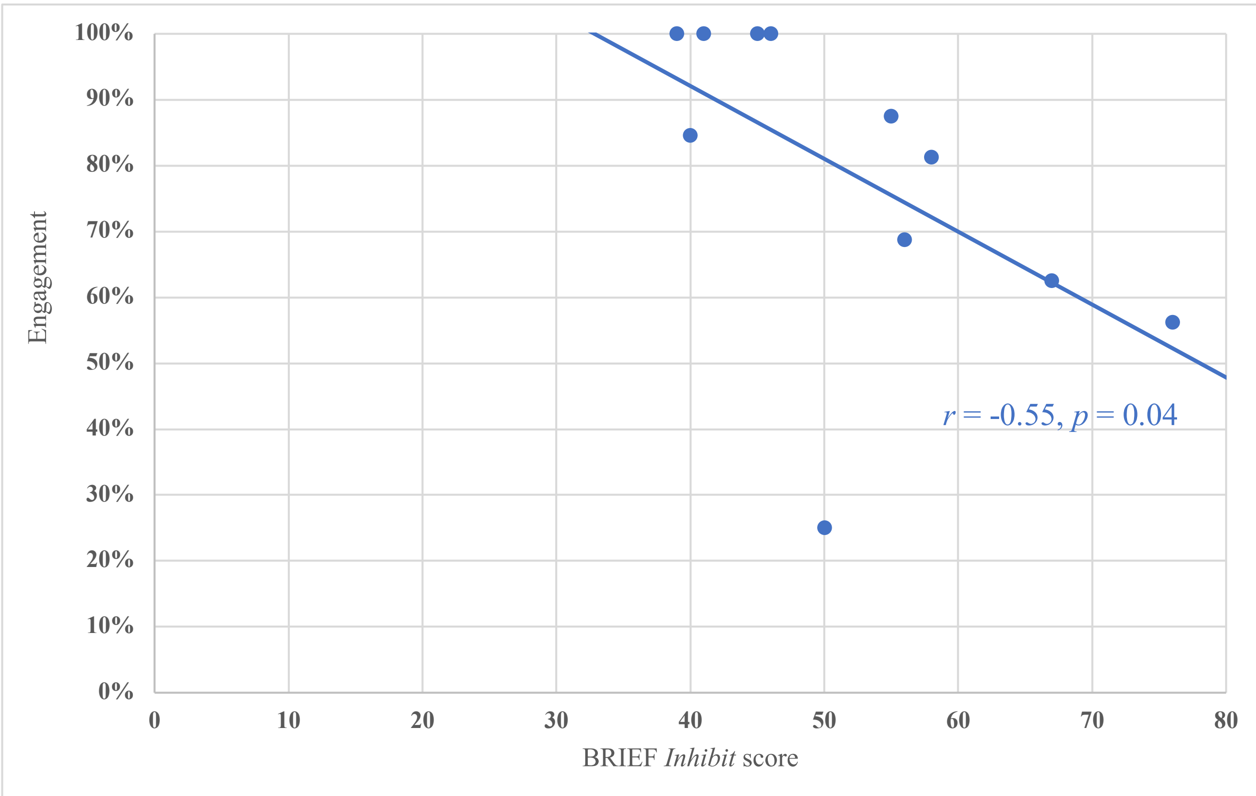

Figure 2a: Correlation between the percentage of intervals participants were engaged with the Toy Frustration Task and BRIEF *Inhibit* score across collapsed groups. A significant negative correlation was found (r = -0.55, p = 0.04).

Figure 2b: Associations between BRIEF *Inhibit* Score and Frustration % Collapsed across Groups

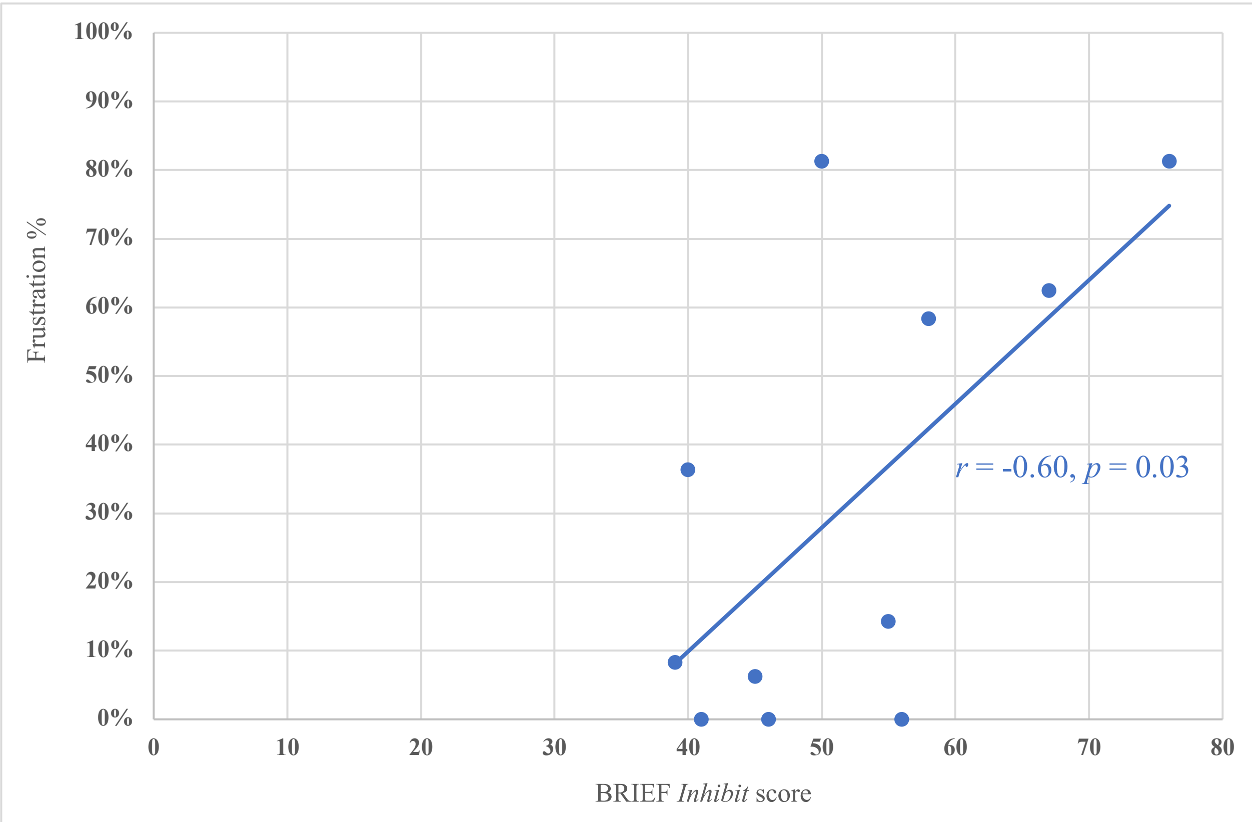

Figure 2b: Correlation between the percentage of intervals participants displayed any degree of frustration (i.e., mild or overt frustration and BRIEF *Inhibit* score across collapsed groups. A significant positive correlation was found ($r = 0.60$, $p = 0.03$).

Figure 2c: Associations between BRIEF *Inhibit* Score and Parent Seeking % Collapsed across Groups

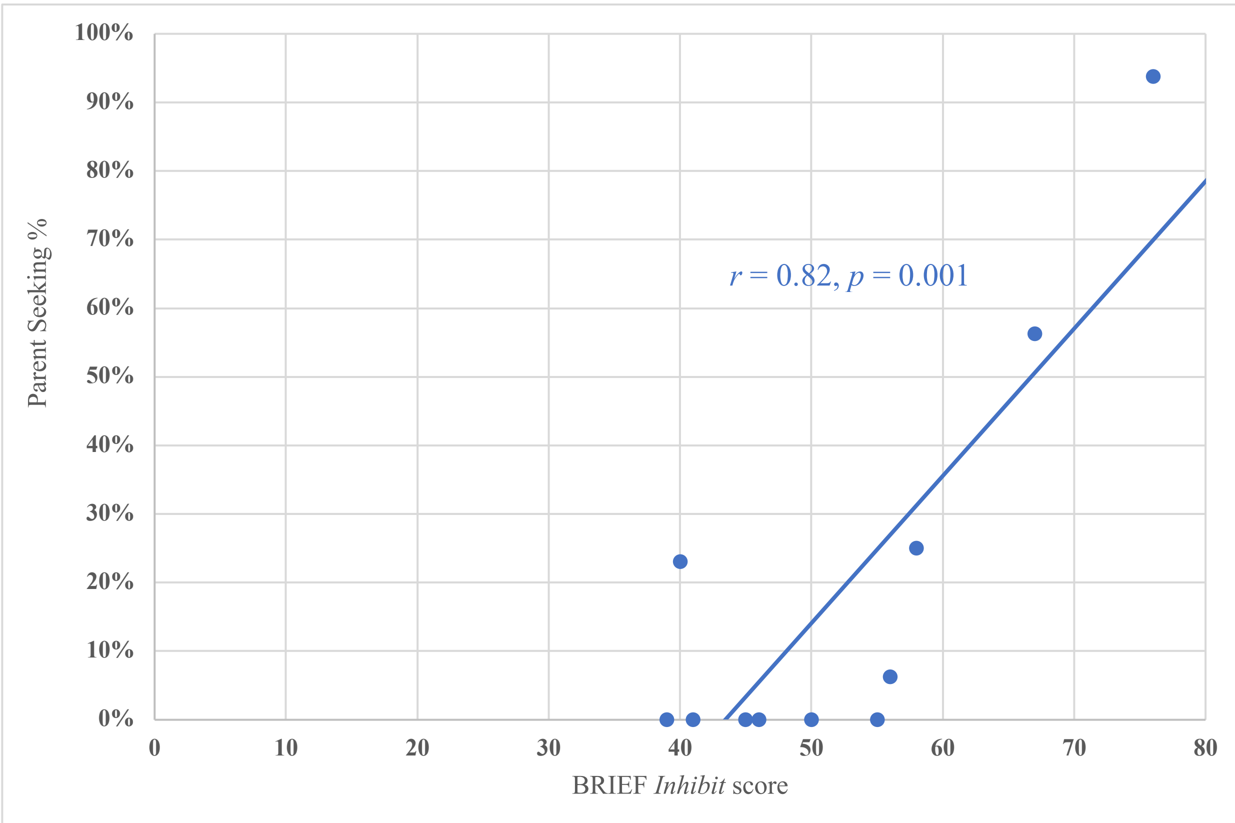

Figure 2c: Correlation between the percentage of intervals participants displayed any degree of parent seek behavior (i.e., low, mild or overt) and BRIEF *Inhibit* score across collapsed groups. A significant positive correlation was found ($r = 0.82$, $p = 0.001$).

Figure 3: Associations between BRIEF Shift Score and Percent Frustration in CI and NH Groups

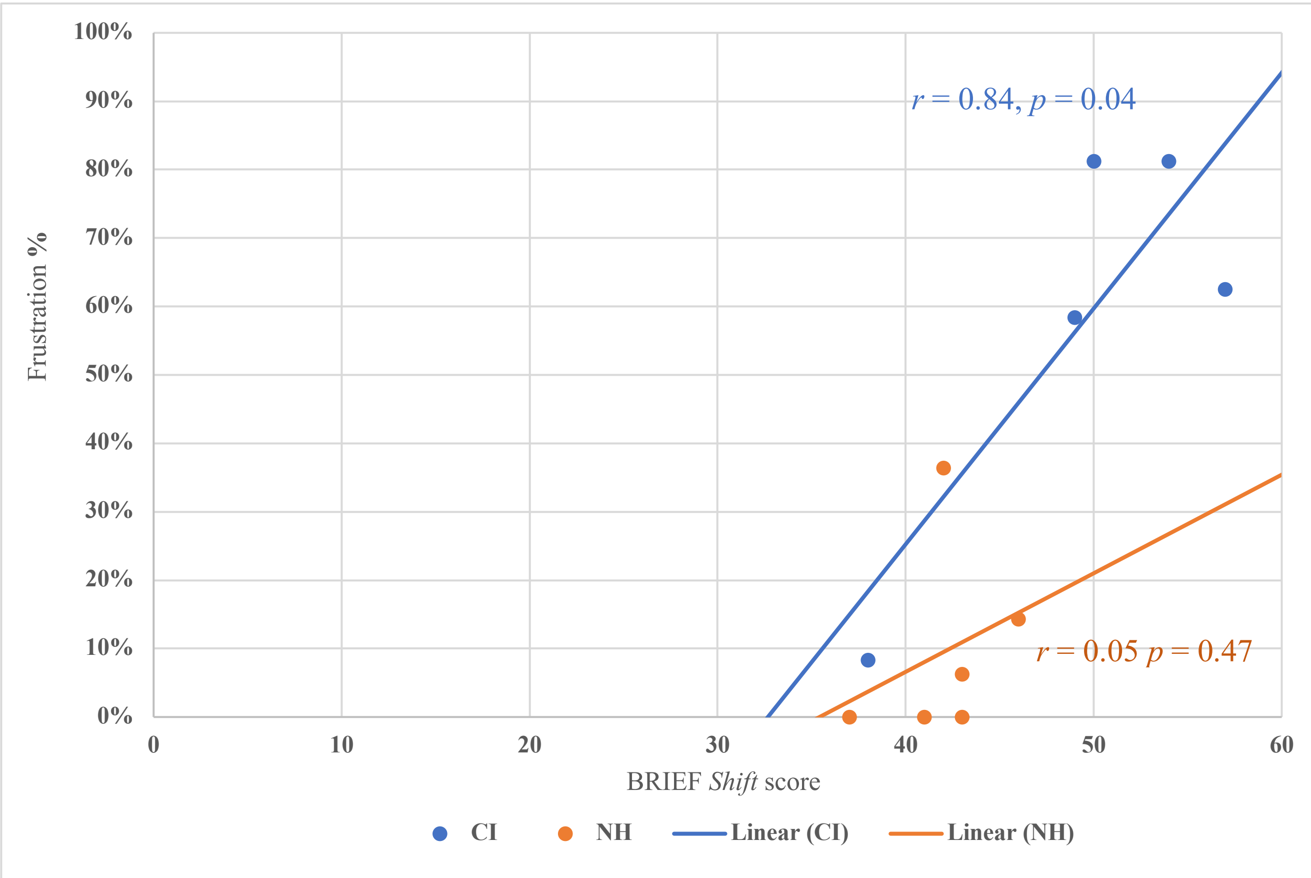

Figure 3: Correlation between the percentage of intervals subjects displayed any degree of frustration (i.e., mild or overt frustration) and BRIEF *Shift* score across CI and NH respectively. A significant positive correlation was found only among CI users ($r = 0.84$, $p = 0.04$). No significant correlation was found for NH users ($r = 0.05$, 0.47).

Figure 4 – Associations Between BRIEF *Inhibit* Score and Parent Seeking % in CI and NH Groups

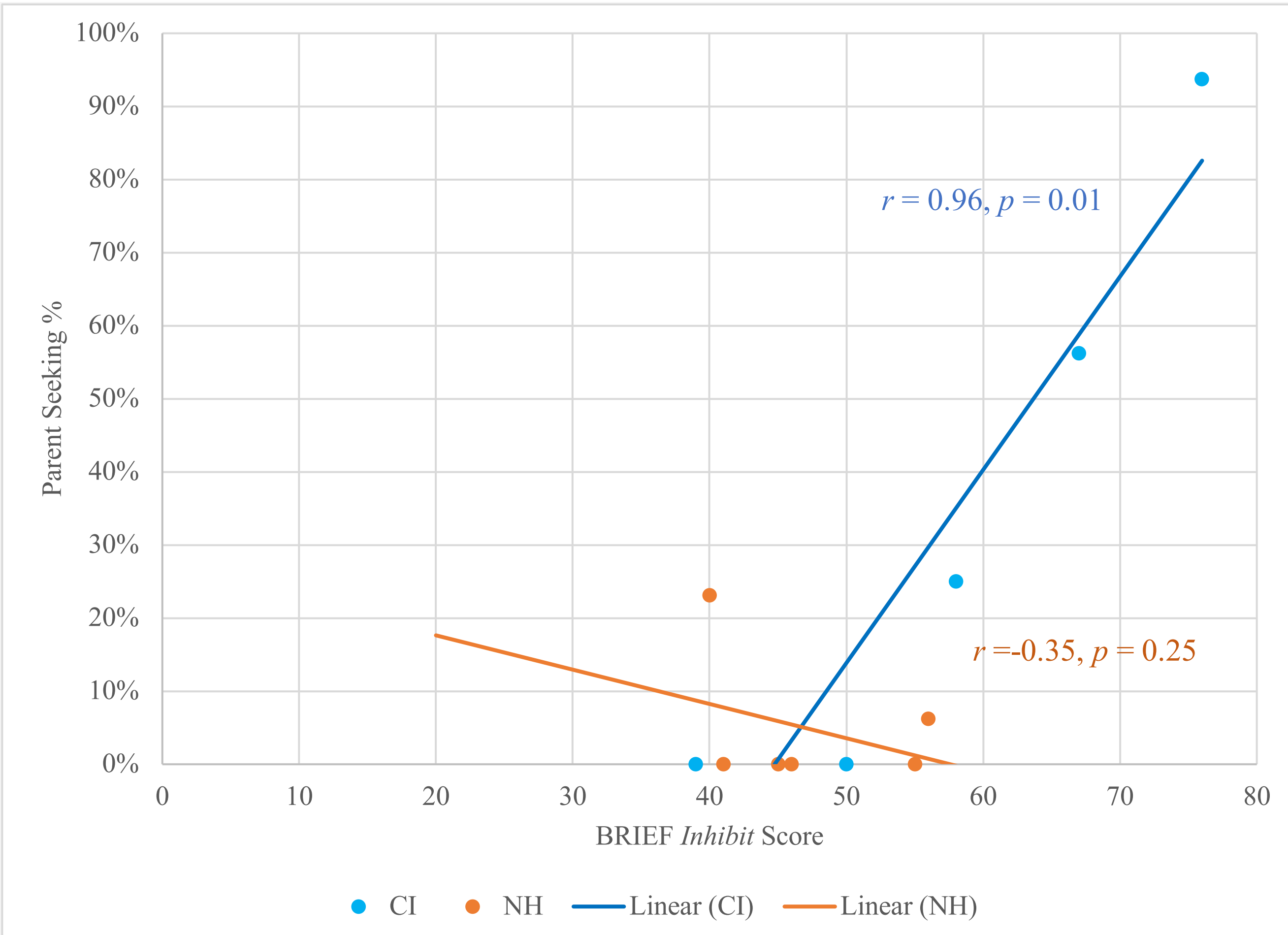

Figure 4: Correlation of BRIEF *Inhibit* score with the percentage of intervals both CI and NH participants displayed any degree of parent/experimenter seeking behavior on the Toy Frustration Task. This resulted in a significant positive correlation for the CI Group ($r = 0.96$, $p = 0.01$), but no significant correlation for the NH group ($r = -0.35$, $p = 0.25$).

Figure 5 – Associations Between BRIEF *Emotional Control* Score and Look Away Duration in CI and NH Groups

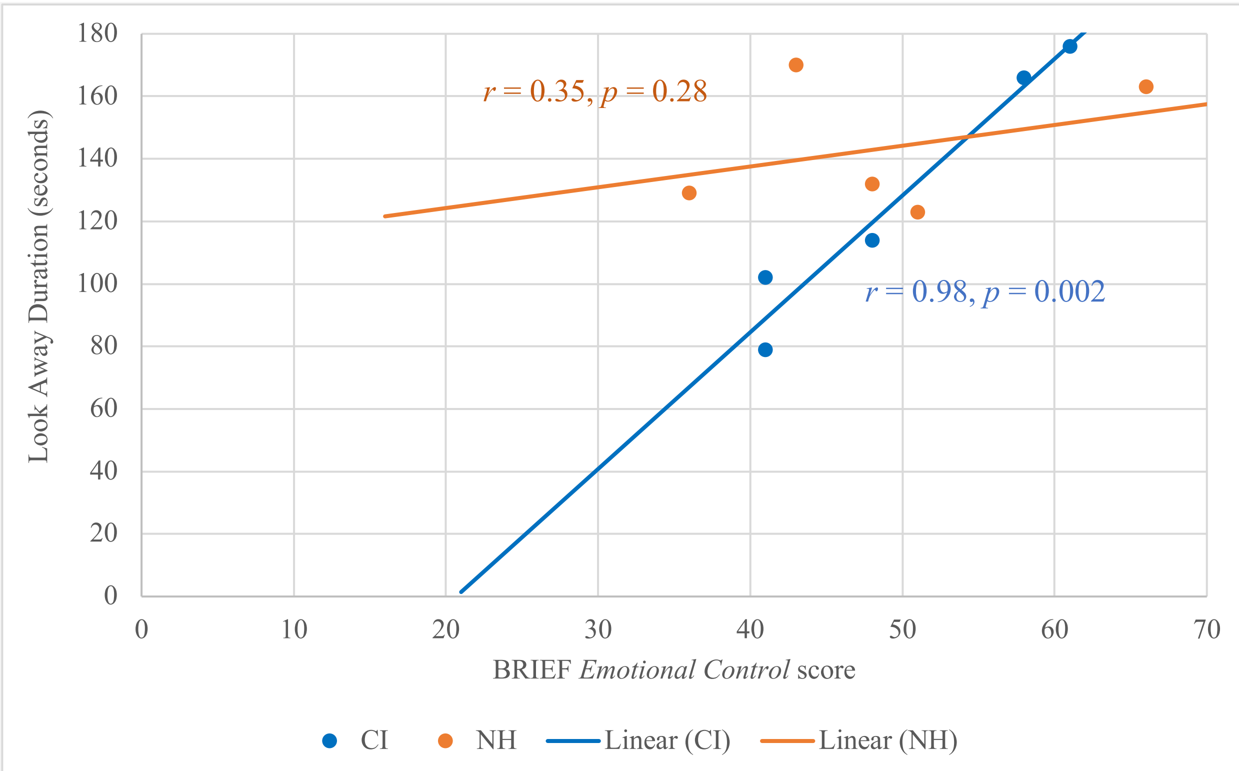

Figure 5: Correlation of BRIEF *Emotional Control* score with the total duration in seconds CI and NH participants look away from the gift bag throughout the task. This resulted in a significant positive correlation for the CI group ($r = 0.98$, $p = 0.002$), and no significant association for the NH group ($r = 0.35$, $p = 0.28$).

Appendix B: Tables

Table. 1 *Participant Demographics*

	Participants (N = 12)	
	Hearing Status	
	CI (N = 6)	NH (N = 6)
	M (SD)	M (SD)
Age at testing (months)	59.37 (*13.60*)	56.73 (*12.58*)
Nonverbal IQ	115 (*19.69*)	118 (*23.05*)
Income level	7.33 (*1.97*)	9.00 (*1.67*)
Maternal education	2.00 (*1.26*)	2.50 (*0.84*)
Gender		
Male	3 (*50.00%*)	1 (*16.67%*)
Female	3 (*50.00%*)	5 (*83.33%*)
Race		
White	5 (83.33%)	5 (*83.33%)*
Asian	1 (*16.67%*)	NA
Mixed Race	NA	1 (*16.67%)*
Ethnicity		
Non-Hispanic	6 (*100%*)	6 (*100%*)

Table 2. *Neurocognitive Metrics*

	Hearing Status			
	CI (N = 6)	NH (N = 6)		
	M(SD)	*M(SD)*	*t*	*p*
PTONI	115.33 (*19.70*)	118.67 (*23.05*)	-0.27	0.79
CELF-P	90.00 (*19.13*)	114.00 (*13.97*)	-2.41	**0.04**

PTONI, Primary Test of Nonverbal Intelligence

CELF, Clinical Evaluation of Language Fundamentals - Preschool

Table 3. *Group differences on Tasks of Hot Inhibitory Control*

	Hearing Status				
	CI (*N* = 5)	NH (*N* = *6)*			
	M (SD)	*M (SD)*	*df*	*t*	*Sig.*
Toy Frustration					
Engagement	0.71 (*0.29*)	0.90 (*0.12*)	10	-1.52	0.16
Mean Frustration	1.77 (*0.72*)	1.09 (*0.16*)	9	2.09	0.07
Percent Frustration	0.51 (*0.33*)	0.11 (0.*15*)	9	2.49	**0.04**
Mean Parent Seeking	0.74 (*0.94*)	0.13 (*0.25*)	10	1.55	0.15
Percent Parent Seeking	0.29 (*0.38*)	0.05 (*0.09*)	10	1.50	0.17
Gift Delay					
Part 1					
Peeking	0.13 (*0.21*)	0.00 (*0.00*)	10	1.46	0.17
Peeking Frequency	1.00 (*2.00*)	0.00 (*0.00*)	10	1.22	0.25
Peeking Duration	2.83 (*4.92*)	0.00 (*0.00*)	10	1.41	0.19
Part 2					
On Seat	0.79 (*0.40*)	1.00 (*0.00*)	10	-1.27	0.23
Look Away Frequency	10.83 (6.*15*)	12.40 (*8.41*)	9	-0.36	0.73
Look Away Duration	123.33 (*38.77*)	143.40 (*21.48*)	9	-1.03	0.33
Touching Bag	0.12 (*0.14*)	0.04 (*0.07*)	10	1.30	0.22
Touching Bag Frequency	1.50 (*1.87*)	1.33 (*2.16*)	10	1.30	0.89
Touching Bag Duration	9.00 (*12.57*)	1.33 (*2.16*)	10	1.47	0.17
Opening/Touching Bag	0.04 (*0.04*)	0.01 (*0.03*)	10	1.20	0.26
Intervals Before Deviance	3.67 (*4.50*)	6.17 (*6.40*)	10	-0.78	0.45

Table 4. *Group differences on BRIEF-P & Flanker*

	Hearing Status			
	CI (N = 5)	NH (N=6)		
	M (*SD)*	M (*SD)*	*t*	*p*
Flanker				
Age Corrected Score	103.60 (*12.68*)	104.00 (*8.37*)	-0.06	0.95
BRIEF Subscales				
Inhibit	58.00 (*14.40*)	47.17 (*6.85*)	1.64	0.13
Shift	49.60 (*7.23*)	42.00 (*2.97*)	2.37	**0.04**
Emotional Control	49.80 (*9.36*)	46.67 (*11.27*)	0.49	0.63

Table 5a. *Pearson Correlations Collapsed Across Groups: Toy Frustration*

	Flanker	Inhibit	Shift	Emotional Control
Toy Frustration				
Engagement				
r	0.42	**-0.55**	**-0.67**	-0.39
p	0.10	**0.04**	**0.01**	0.12
N	11	11	11	11
Mean Frustration				
r	-0.35	**0.6**	**0.79**	0.37
p	0.16	**0.03**	**0.003**	0.14
N	10	10	10	10
Percent Frustration				
r	-0.13	**0.60**	**0.83**	0.26
p	0.36	**0.03**	**0.002**	0.23
N	10	10	10	10
Mean Parent Seeking				
r	-0.35	**0.82**	**0.76**	**0.47**
p	0.15	**0.001**	**0.004**	**0.07**
N	11	11	11	11
Percent Parent Seeking				
r	-0.33	**0.83**	**0.73**	**0.48**
p	0.16	**0.001**	**0.01**	**0.07**
N	11	11	11	11

Table 5b. *Pearson Correlations Collapsed Across Groups: Gift Delay Part 1*

	Flanker	Inhibit	Shift	Emotional Control
Gift Delay Pt. 1				
Peeking				
r	-0.02	0.35	0.45	-0.07
p	0.47	0.14	0.08	0.42
N	11	11	11	11
Peeking Frequency				
r	0.13	0.25	0.30	-0.17
p	0.35	0.23	0.18	0.31
N	11	11	11	11
Peeking Duration				
r	0.02	0.33	0.41	-0.09
p	0.48	0.16	0.10	0.39
N	11	11	11	11

Table 5c: *Pearson Correlations for CI Users: Gift Delay Part 2*

	Flanker	Inhibit	Shift	Emotional Control
Gift Delay Pt. 2				
On Seat				
r	0.16	**-0.66**	-0.50	-0.42
p	0.32	**0.01**	0.06	0.10
N	11	11	11	11
Look Away Frequency				
r	0.40	-0.40	**-0.58**	**-0.66**
p	0.13	0.13	**0.04**	**0.02**
N	10	10	10	10
Look Away Duration				
r	-0.41	0.39	0.34	**0.64**
p	0.12	0.13	0.17	**0.02**
N	10	10	10	10
Touching Bag				
r	0.33	0.07	0.39	-0.14
p	0.16	0.42	0.12	0.34
N	11	11	11	11
Touching Bag Freq.				
r	0.23	-0.04	0.24	-0.06
p	0.25	0.45	0.24	0.43
N	11	11	11	11
Touching Bag Duration				
r	0.28	0.06	0.34	-0.15
p	0.20	0.43	0.15	0.33
N	11	11	11	11
Opening/Peeking in Bag				
r	-0.12	-0.06	-0.03	-0.32
p	0.36	0.43	0.47	0.17
N	11	11	11	11
Intervals Before Deviance				
r	-0.23	0.19	-0.01	0.23
p	0.25	0.29	0.49	0.25
N	11	11	11	11

Table 6a. *Pearson Correlations for CI Users: Toy Frustration*

	Flanker	Inhibit	Shift	Emotional Control
Toy Frustration				
Engagement				
r	0.62	-0.32	-0.60	-0.47
p	0.13	0.30	0.14	0.21
N	5	5	5	5
Mean Frustration				
r	-0.64	0.61	0.73	**0.83**
p	0.12	0.14	0.08	**0.04**
N	5	5	5	5
Percent Frustration				
r	-0.45	0.71	**0.84**	0.62
p	0.22	0.09	**0.04**	0.13
N	5	5	5	5
Mean Parent Seeking				
r	-0.60	**0.96**	0.74	**0.86**
p	0.14	**0.01**	0.08	**0.03**
N	5	5	5	5
Percent Parent Seeking				
r	-0.55	**0.95**	0.70	**0.86**
p	0.17	**0.01**	0.09	**0.03**
N	5	5	5	5

Table 6b. *Pearson Correlations for CI Users: Gift Delay Part 1*

	Flanker	Inhibit	Shift	Emotional Control
Gift Delay Pt. 1				
Peeking				
r	-0.02	0.17	0.24	-0.28
p	0.49	0.39	0.35	0.32
N	5	5	5	5
Peeking Frequency				
r	0.19	0.07	0.07	-0.44
p	0.38	0.45	0.46	0.23
N	5	5	5	5
Peeking Duration				
r	0.04	0.15	0.20	-0.33
p	0.47	0.41	0.38	0.30
N	5	5	5	5

Table 6c. *Pearson Correlations for CI Users: Gift Delay Part 2*

	Flanker	Inhibit	Shift	Emotional Control
Gift Delay Pt. 2				
On Seat				
r	0.20	-0.64	-0.36	-0.66
p	0.37	0.12	0.28	0.11
N	5	5	5	5
Look Away Frequency				
r	0.49	**-0.83**	**-0.89**	**-0.87**
p	0.20	**0.04**	**0.02**	**0.03**
N	5	5	5	5
Look Away Duration				
r	-0.68	0.75	0.67	**0.98**
p	0.10	0.07	0.11	**0.002**
N	5	5	5	5
Touching Bag				
r	0.39	-0.22	0.13	-0.38
p	0.26	0.36	0.42	0.26
N	5	5	5	5
Touching Bag Frequency				
r	0.39	-0.26	0.14	-0.24
p	0.26	0.34	0.41	0.35
N	5	5	5	5
Touching Bag Duration				
r	0.35	-0.26	0.03	-0.45
p	0.28	0.33	0.48	0.22
N	5	5	5	5
Opening/Peeking in Bag				
r	-0.46	-0.32	-0.30	-0.46
p	0.22	0.30	0.31	0.22
N	5	5	5	5
Intervals Before Deviance				
r	-0.10	0.71	0.36	0.76
p	0.43	0.09	0.28	0.07
N	5	5	5	5

Table 7a. *Pearson Correlations for NH Group: Toy Frustration*

	Flanker	Inhibit	Shift	Emotional Control
Toy Frustration				
Intervals Engaged				
r	0.09	-0.61	-0.09	-0.31
p	0.43	0.10	0.43	0.27
N	6	6	6	6
Mean Frustration				
r	0.66	-0.75	-0.31	-0.41
p	0.11	0.07	0.31	0.25
N	5	5	5	5
Percent Frustration				
r	0.59	-0.56	0.05	-0.07
p	0.15	0.16	0.47	0.46
N	5	5	5	5
Mean Parent Seeking				
r	0.38	-0.39	-0.04	-0.15
p	0.23	0.22	0.47	0.39
N	6	6	6	6
Percent Parent Seeking				
r	0.37	-0.35	-0.04	-0.15
p	0.23	0.25	0.47	0.39
N	6	6	6	6

Table 7b. *Pearson Correlations for NH Group: Gift Delay Part 2*

	Flanker	Inhibit	Shift	Emotional Control
Gift Delay Pt. 2				
Look Away Frequency				
r	0.34	0.26	-0.38	-0.54
p	0.29	0.33	0.26	0.17
N	5	5	5	5
Look Away Duration				
r	0.39	-0.14	0.34	0.35
p	0.26	0.41	0.29	0.28
N	5	5	5	5
Touching Bag				
r	0.27	0.11	0.47	-0.07
p	0.30	0.42	0.17	0.45
N	6	6	6	6
Touching Bag Frequency				
r	0.22	0.17	0.53	0.04
p	0.34	0.37	0.14	0.47
N	6	6	6	6
Touching Bag Duration				
r	0.22	0.17	0.53	0.04
p	0.34	0.37	0.14	0.47
N	6	6	6	6
Opening/Peeking in Bag				
r	0.41	-0.44	**-0.83**	-0.46
p	0.21	0.19	**0.02**	0.18
N	6	6	**6**	6
Intervals Before Deviance				
r	-0.38	0.02	0.01	0.04
p	0.23	0.49	0.49	0.47
N	6	6	6	6

Figure 7: No NH participants engaged in Peeking Behaviors on Gift Delay Part 1. Furthermore, all NH participants remained On Seat for the entirety for both Gift Delay Part 1 and Part 2. Thus, these metrics were omitted.